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NCSP
NUCLEAR CRITICALITY SAFETY PROGRAM

Thermal Epithermal eXperiments (TEX) Subcritical Experiment Results with Plutonium-Aluminum Zero Power Physics Reactor (ZPPR) and Polyethylene

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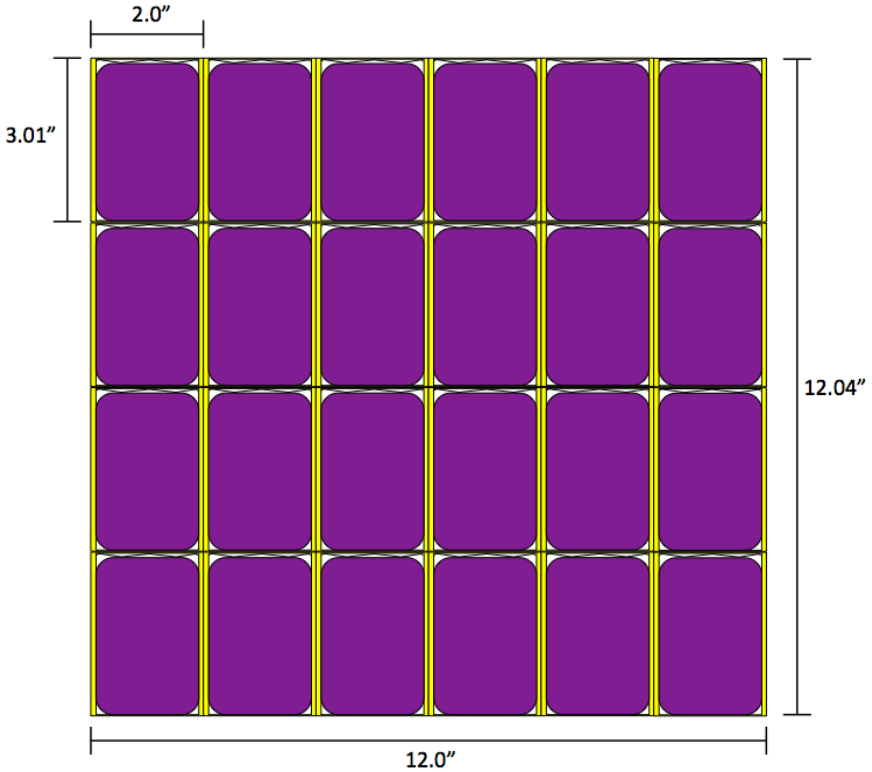
IER 184: Thermal/Epithermal eXperiments (TEX)

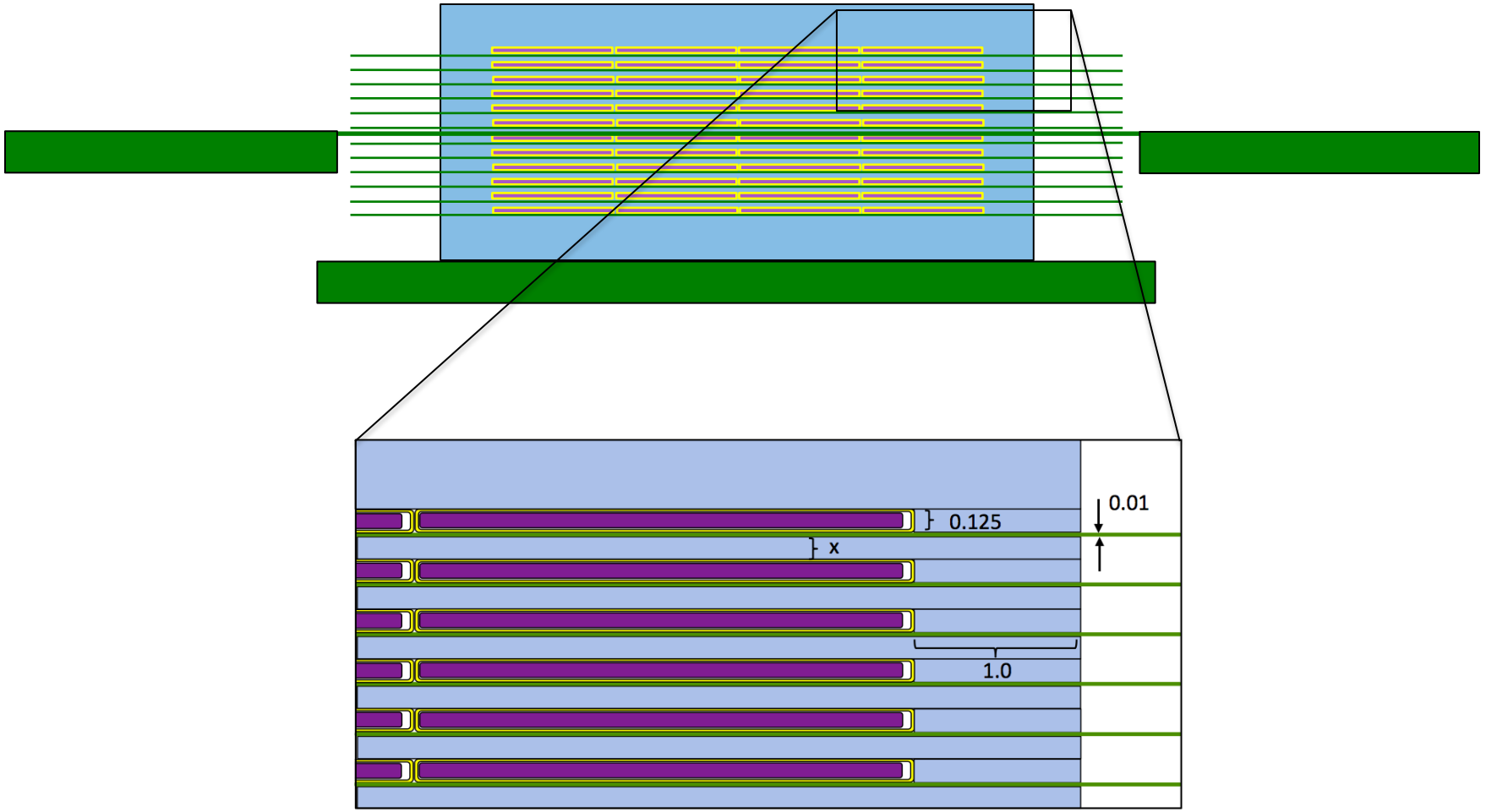
- TEX Motivation
  - July 2011 at Sandia National Laboratories, Albuquerque, NM
    - Representatives from US, UK, and France in nuclear criticality safety, critical experiments, and nuclear data
    - Intermediate spectrum experiments needed
      - Limited Data (2.1% of ICSBEP Benchmarks)
    - Consensus prioritization of nuclear data needs (in order):
      - ^{239}Pu, ^{240}Pu, ^{238}U, ^{235}U, Temperature variations, Water density variations, Steel, Lead (reflection), Hafnium, Tantalum, Tungsten, Nickel, Molybdenum, Chromium, Manganese, Copper, Vanadium, Titanium, and Concrete (reflection, characterization, and water content)
- CED-2 (FY14) showed Final Design of TEX experiments using Zero Power Physics Reactor (ZPPR) Pu-Al plates moderated by polyethylene with tantalum diluents
- **FY2015: First subcritical experiment to test heat dispersal plates and investigate personnel dose concerns**

Final Design Plutonium Baseline Experiments

- Five experiments, covering thermal, intermediate and fast fission energy regimes
- PANN plates arranged in approximately 12” x 12” layers (6 plates by 4 plates)

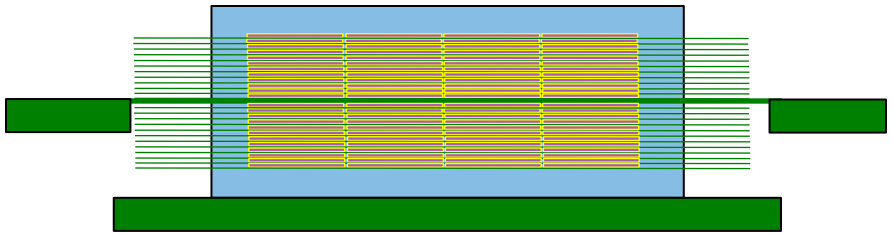


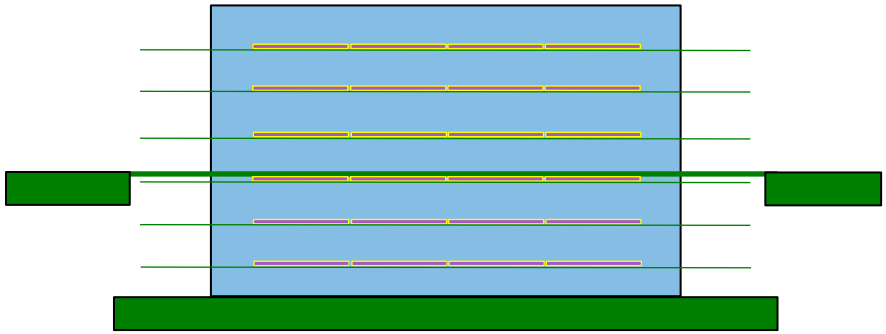
Plutonium Baseline Experiments



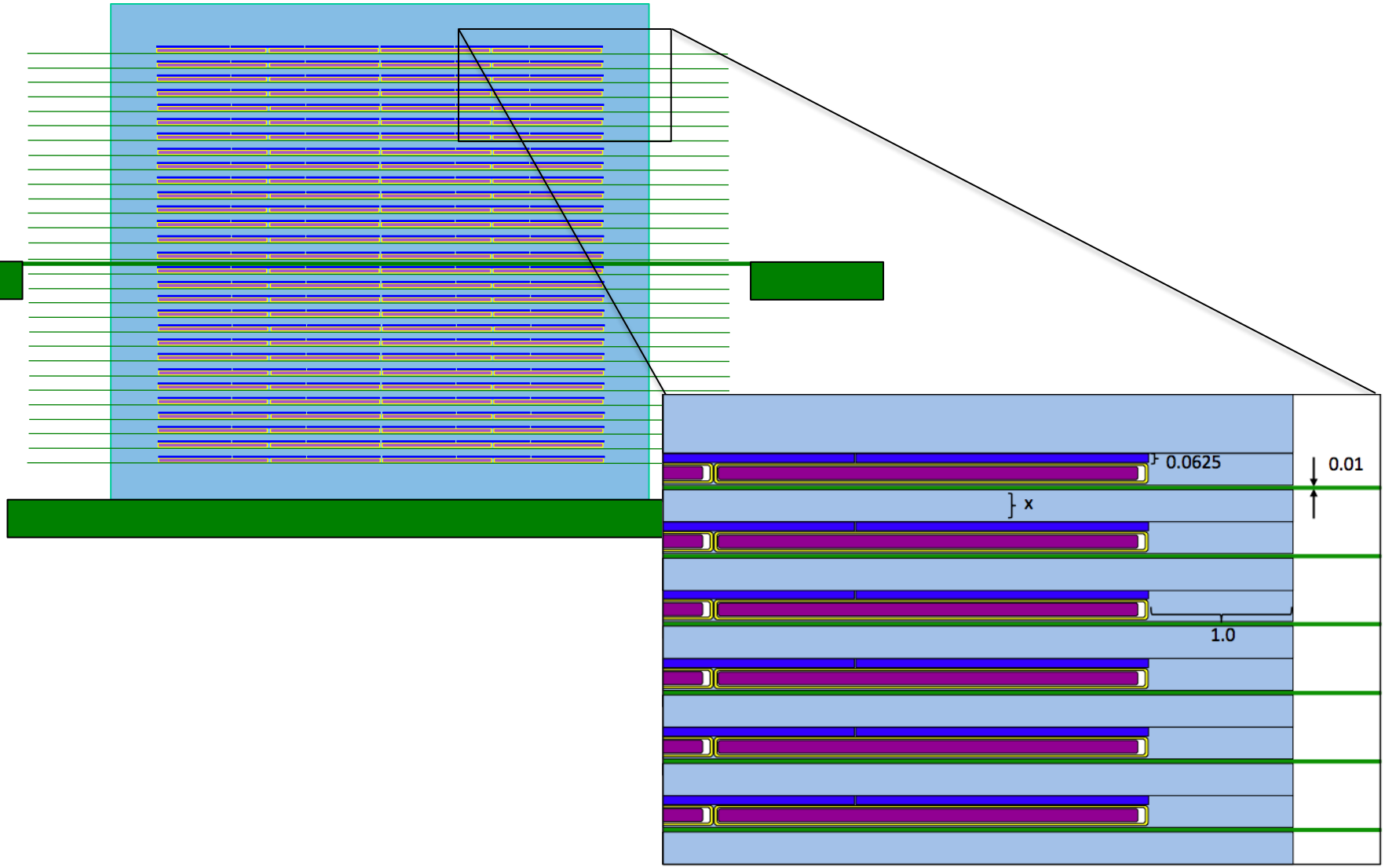
Baseline Experiment Characteristics

Thickness of PE Plates (in)	Critical Mass (kg ^{239}Pu)	Number of Pu Layers	Number of ZPPR Plates	Stack Height (cm)	Thermal Fission Fraction (<0.625 eV)	Intermediate Fission Fraction (0.625 eV-100 KeV)	Fast Fission Fraction (>100 KeV)
0 (no PE)	49.8	21	504	12.5	0.09	0.17	0.74
1/16	40.3	17	408	13.5	0.14	0.38	0.49
3/16	28.5	12	288	12.0	0.27	0.43	0.30
7/16	19.0	8	192	15.9	0.48	0.33	0.19
1	14.2	6	144	20.5	0.67	0.21	0.12



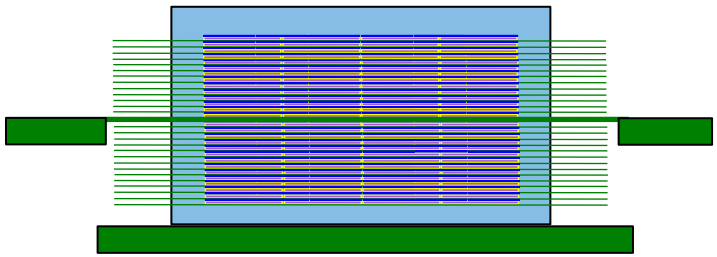


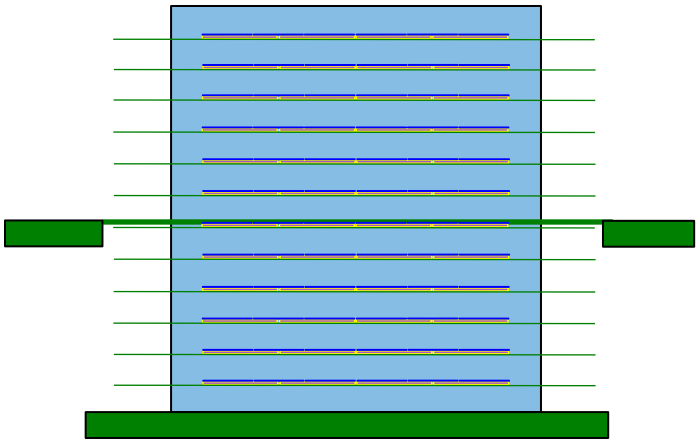
Tantalum Diluent Experiments



Tantalum Experiment Characteristics

Thickness of PE Plates (in)	Critical Mass (kg ^{239}Pu)	Number of Pu Layers	Number of ZPPR Plates	Stack Height (cm)	Thermal Fission Fraction (<0.625 eV)	Intermediate Fission Fraction (0.625 eV-100 KeV)	Fast Fission Fraction (>100 KeV)
0 (no PE)	61.7	26	624	13.0	0.07	0.14	0.79
1/16	71.2	30	720	19.6	0.8	0.36	0.56
3/16	68.8	29	696	29.3	0.19	0.45	0.36
7/16	42.7	18	432	33.1	0.43	0.36	0.21
1	28.5	12	288	36.3	0.64	0.22	0.14





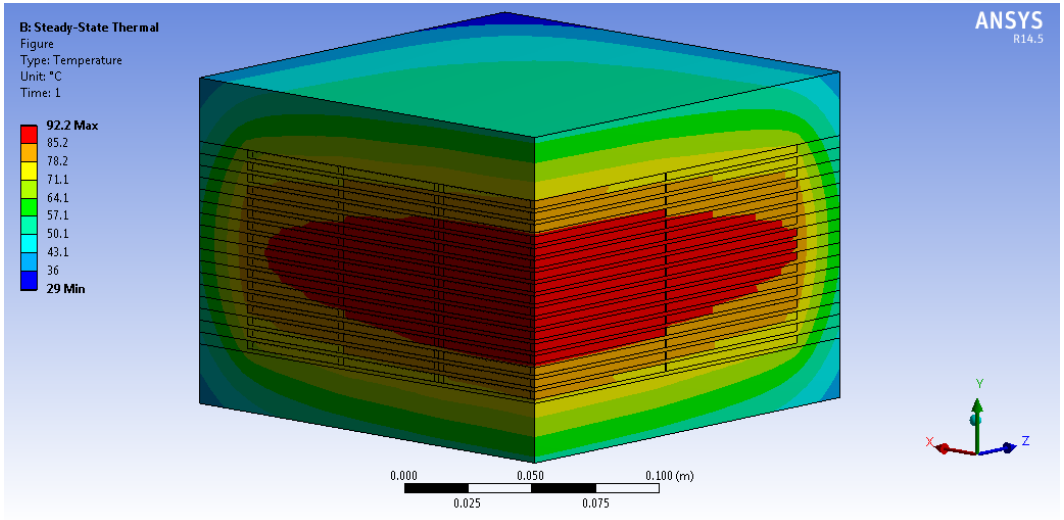
Heat Load Calculations

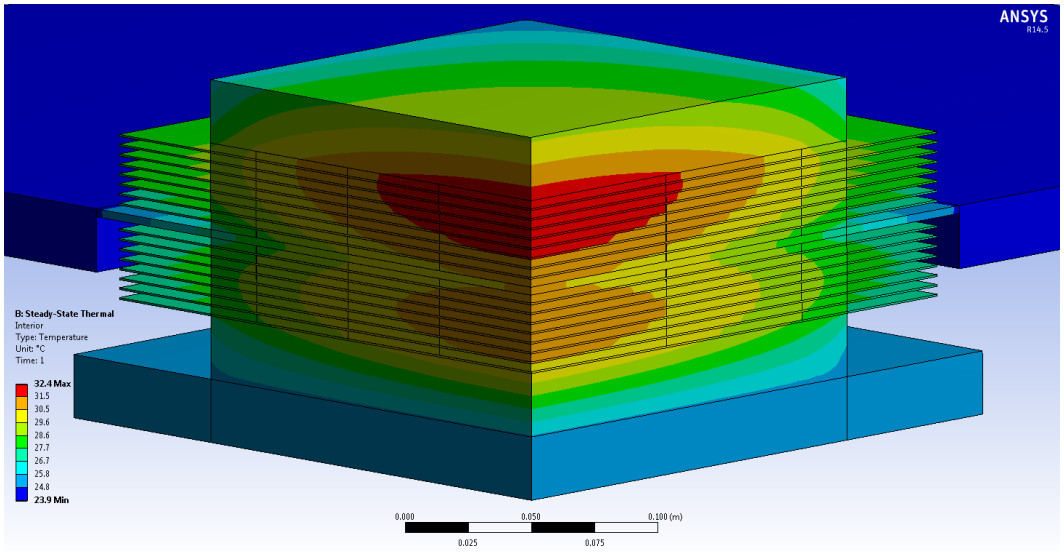
- Tens of kg quantities of Plutonium plates required for TEX configurations produce lots of heat

Isotope	Mass per ZPPR Plate (g)	Specific Power (mW/g)[14]	Heat Source (mW)
^{239}Pu	98.87	1.9288	190.700456
^{240}Pu	4.697	7.0824	33.2660328
^{241}Pu	0.0032	3.412	0.0109184
^{242}Pu	0.0049	0.1159	0.00056791
^{241}Am	0.4021	114.2	45.91982
Total	**103.9772**		**269.8977951**

- Heat load calculations were completed to ensure temperatures would not impact the polyethylene moderators (maximum long-term service life temperature of 80 °C)

Heat Load Calculations





- ANSYS 14.5.0 Finite Element Analysis Software used to model TEX configurations with PE moderation
  - Without 0.01” aluminum heat dispersal plates
  - With 0.01” aluminum heat dispersal plates (“fins”)

Heat Load Results

Experiment Modeled	HDPE Thickness (in)	Pu Layers	T_{max} Without Fins (°C)	T_{max} With Fins (°C)
1	0	21	32.6	
2	1/16	17	52.6	36.3
3	3/16	12	44.9	34.6
4	7/16	8	39.1	32.7
5	1	6	36.6	31.8

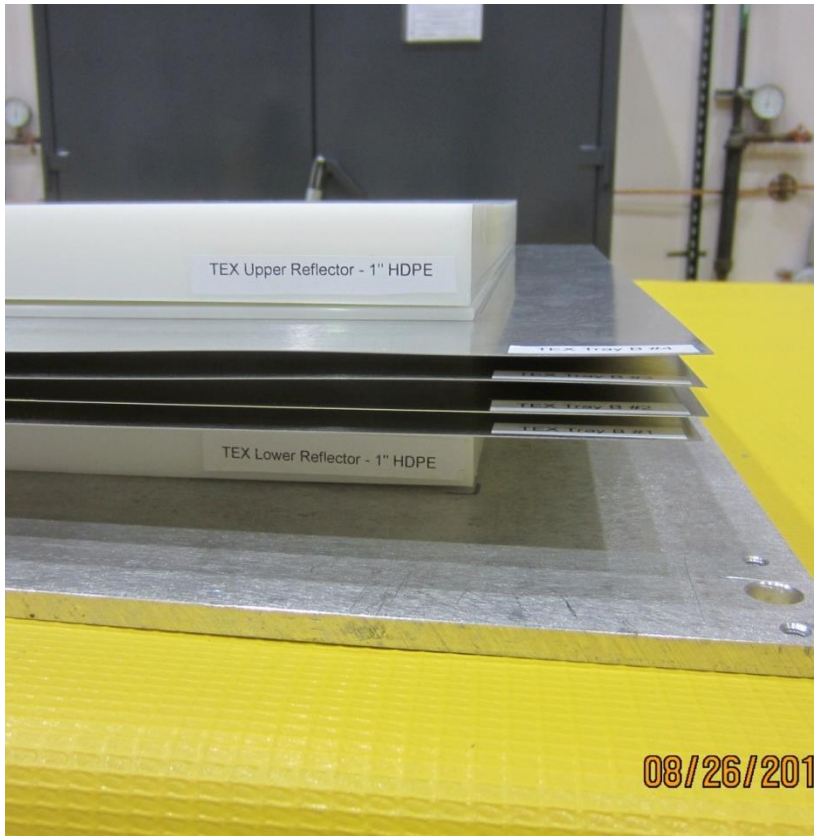
- T_{max} without fins 52.6°C
- Maximum long-term service temperature of HDPE is approximately 80 °C
- Fins likely not required to keep temperature below polyethylene impact temperature
- However, fins help normalize temperature over entire stack and over the five different experiments

Subcritical Experiment Operations

- Build 4 layers of assembly of ZPPR plates (24 plates per layer) with 1/16” polyethylene moderation between each layer

- Data Goals for Experiment:
  - **Weight and external dimensions for 20% of the plates-** for quantification of experimental uncertainties
  - **Temperature measurements over the assembly-** check the utility of the fins
  - **Contact and 30 cm γ/n dose rates for individual plate and assembly-** help with ALARA planning for critical experiment
  - **γ/n doses to personnel-** help with ALARA planning for critical experiment

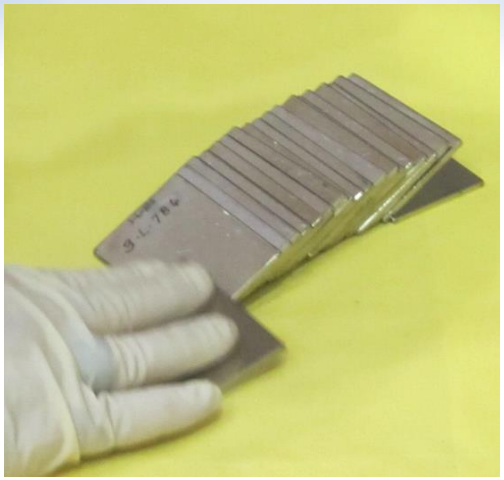
August 2015 Subcritical TEX Experiment



Metrology Data

- Historical ZPPR Data
  - Average Plate Net Weight:

    130.148 ± 0.248 g
  - Dimensional measurements- no records found, but INL used go-no-go gauges for acceptance testing, 3.01”, 2.00”, and 0.25”

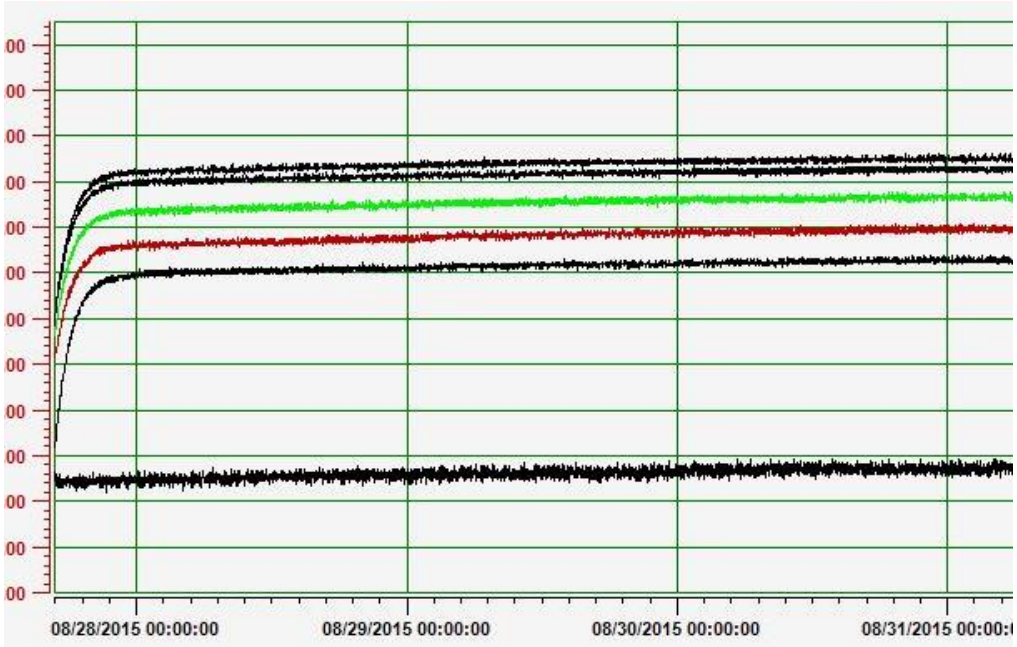


- Measured 20 plates out of population of 100, including weight and dimensional measurements with digital caliper

	Weight	Width (in)	Length (in)	Height (in)
Min	129.400	1.985	2.997	0.111
Max	130.700	1.998	3.009	0.121
Avg	130.185	1.993	3.002	0.117
Std	0.317	0.004	0.003	0.002

- Excellent agreement with historical data!

Temperature Results



Thermocouple Location	Max Temperature (°C)
Layer 1	35.95
Layer 2	37.38
Layer 3	38.53
Layer 4	38.85
Top of Assembly	34.42
Ambient	25.58

- Peak of 38.85°C with ambient temperature of 25.58°C (13.27°C ΔT)
  - Good agreement with predicted peak temperature of 36.3°C with ambient temperature of 22°C (14.3°C ΔT)
- Assembly reached equilibrium temperature after approximately 7 hours
- Confirms flat temperature profile over assembly

Dose Concerns and ALARA Planning

- Detailed Time-In-Motion study completed
  - Used limited gamma/neutron (γ/n) instrument measurement data from INL ZPPR packaging operation
  - Walked through each step of operation with real operators

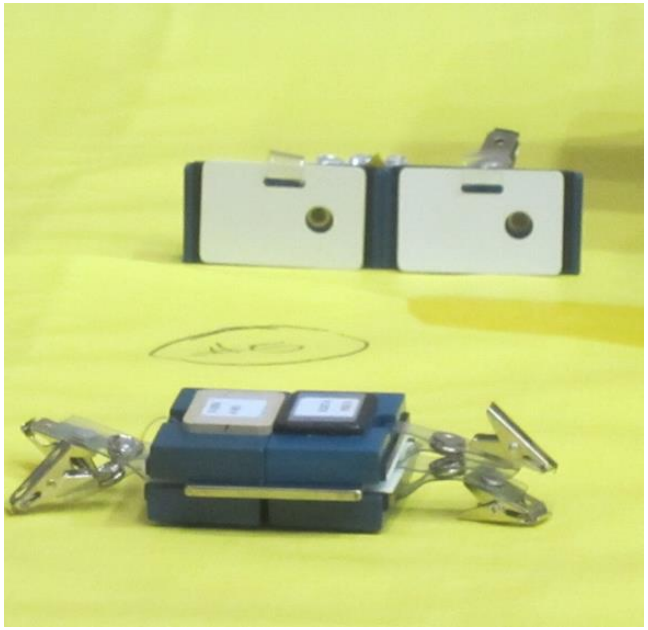
Task	Time (s)	Whole Body Distance	Gamma Dose Rate (mrem/hr)	Neutron Dose Rate (mrem/hr)	Estimated Whole Body Dose	Extremity Distance	Gamma Dose Rate (mrem/hr)	Neutron Dose Rate (mrem/hr)	Estimated Extremity Dose
SAVY Can 1									
Verify item number on SAVY can	11	1 m	0.72	0.27	0.003025	1 m	0.72	0.27	0.003025
Verify TID	8	30 cm	8	3	0.024444	30 cm	8	3	0.024444444
Pick up SAVY and place on cart	10	30 cm	8	3	0.030556	Hands on	60	8	0.188888889
Move cart to assembly table	25	30 cm	8	3	0.076389	30 cm	8	3	0.076388889
Remove TID	6	30 cm	8	3	0.018333	Hands on	60	8	0.113333333
Open SAVY container	25	30 cm	8	3	0.076389	Hands on	60	8	0.472222222
Pull out tray	10	30 cm	323	137.8	1.28	hands on	800	1400	6.111111111
Flatten plates out, serial facing up	16	30 cm	323	137.8	2.048	hands on	800	1400	9.777777778
MC&A Verification	360	30 cm	323	137.8	46.08	30 cm	230	137.8	36.78
Place four plates on cart	12	30 cm	323	137.8	1.536	hands on	300	900	4
Move cart to measuement table	19	30 cm	323	137.8	2.432	30 cm	230	30	1.372222222
weigh four plates	26	30 cm	323	137.8	3.328	hands on	300	900	8.666666667
measure four plates' dimensions	84	30 cm	323	137.8	10.752	hands on	300	900	28
Place four plates on cart	12	30 cm	323	137.8	1.536	hands on	300	900	4
Move cart to assembly table	19	30 cm	323	137.8	2.432	30 cm	323	137.8	2.432
Assemble tray 1	44	30 cm	323	137.8	5.632	hands on	800	1400	26.88888889
Move Tray 1 to cart	15	30 cm	323	137.8	1.92	hands on	800	1400	9.166666667
Additional time between ops	600	1 m	20.7	12.4	5.516667	1 m	20.7	12.4	138.0706111
Total	**1302**				**84.7218**				**276.1442472**
SAVY Can 2									
Verify item number on SAVY can	11	1 m	0.72	0.27	0.003025	1 m	0.72	0.27	0.003025
Verify TID	8	30 cm	8	3	0.024444	30 cm	8	3	0.024444444
Pick up SAVY and place on cart	10	30 cm	8	3	0.030556	Hands on	60	8	0.188888889
Move cart to assembly table	25	30 cm	8	3	0.076389	30 cm	8	3	0.076388889
Remove TID	6	30 cm	8	3	0.018333	Hands on	60	8	0.113333333
Open SAVY container	25	30 cm	8	3	0.076389	Hands on	60	8	0.472222222
Pull out tray	10	30 cm	323	137.8	1.28	hands on	800	1400	6.111111111

- Conservative estimation of doses for entire activity:
  - 600 mrem Whole Body Dose
  - 2100 mrem Extremity Dose

Results from Dosimeters

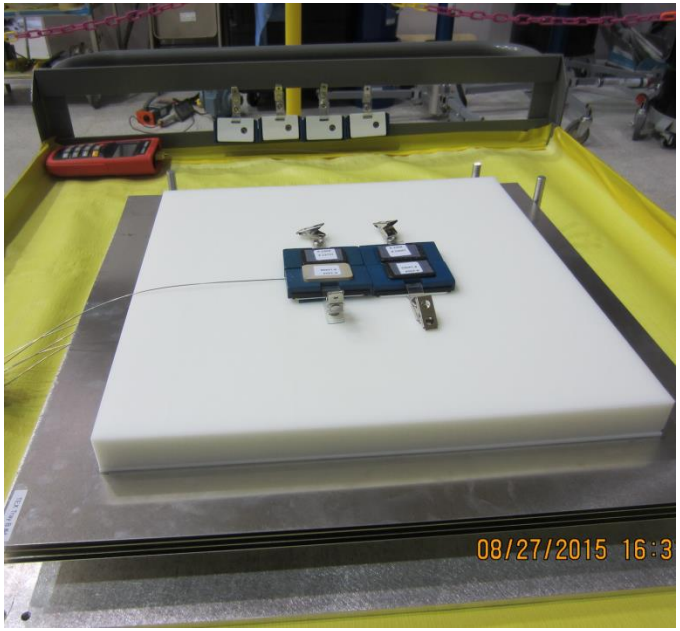
- Deployed LLNL TLD dosimeters with CR-39 neutron dosimeters to take contact and 30 cm dose measurements

Single ZZPR Plate



Contact: 721.7 mrem/hr γ
9.6 mrem/hr n
30 cm: 0.70 mrem/hr γ
0.20 mrem/hr n

Assembly



Contact: 703.2 mrem/hr γ
44.9 mrem/hr η
30 cm: 11.7 mrem/hr γ
2.2 mrem/hr η

Personnel Doses

- Operators (fissile material handers) were issued task dosimetry and finger rings
- Operators and other personnel (RCT, MC&A, etc) were issued Electronic Personal Dosimeters (EPDs)

Dosimeter Type	γ/n Dose to All Monitored (mrem)
EPD	42.87
Combo TLD (Operators only)	61
Finger Rings (Operator only)	253

- Less than 100 mrem Whole Body to all participants for the entire operation

Subcritical Experiment Conclusions

- Successfully met 4 goals for the experiment:
  - **Weight and external dimensions for 20% of the plates-** very good agreement with historical net weight information and provided missing information regarding actual plate sizes
  - **Temperature measurements over the assembly-** Fins seemed to work and we have good agreement with simulated results
  - **Contact and 30 cm γ/n dose rates for individual plates and assembly-** more realistic dose rates will allow for more accurate ALARA planning
  - γ/n **doses to personnel-** Due to careful work planning, good ALARA practice, and professional fissile material handlers, doses were significantly lower than conservative estimates

Current Work for TEX

- Fabrication of experimental trays, moderators, and experimental fixturing is complete
- Experimental plan is complete and has been submitted to facility stakeholders
- Upon approval of experiment plan, the first two experiments are ready to schedule for execution in Q3/Q4 of FY2016